1.4 Harvesting Nuclear Energy

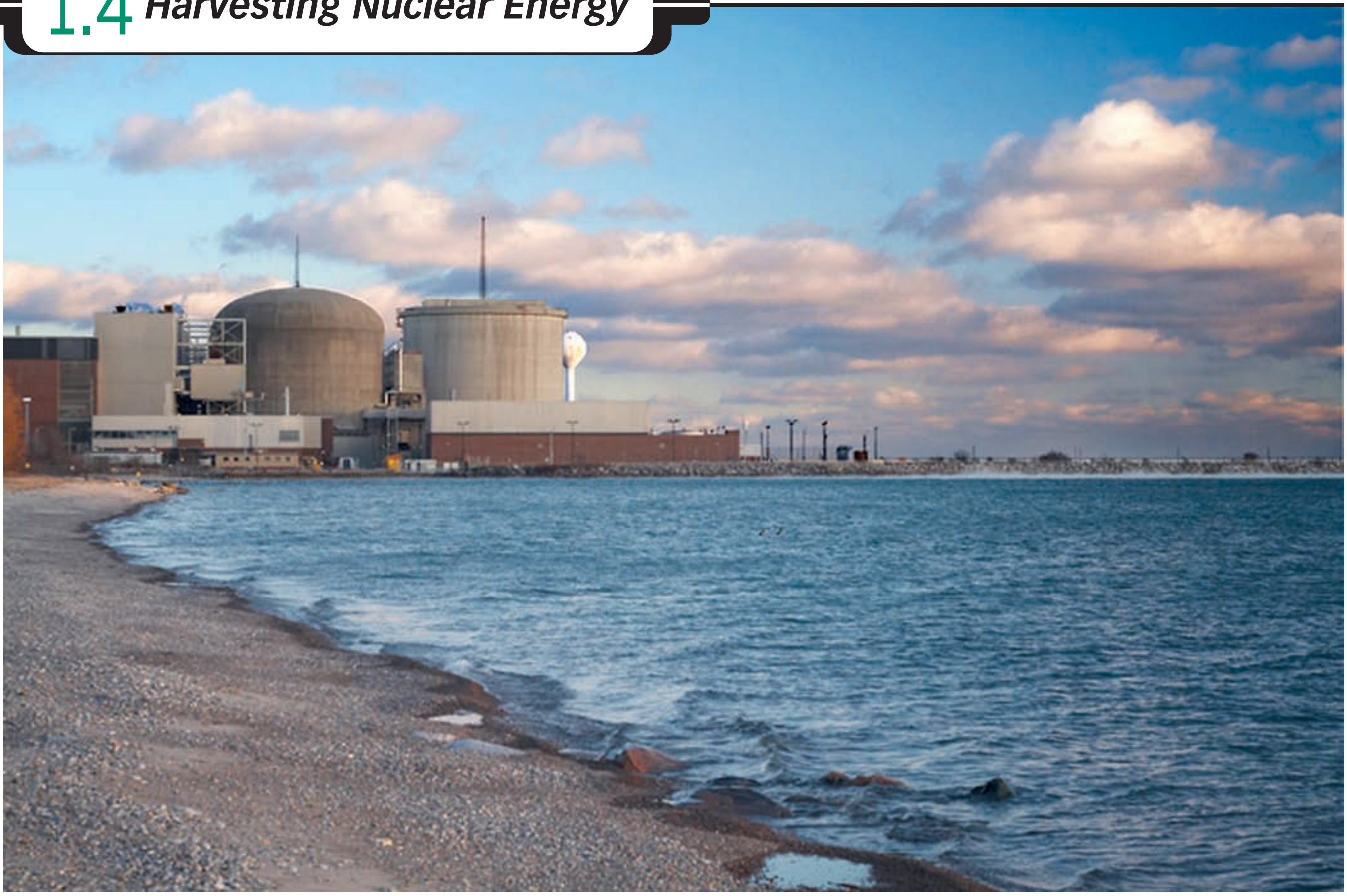


Figure D1.30: Pickering, Ontario, is home to one of the world's largest nuclear power facilities.

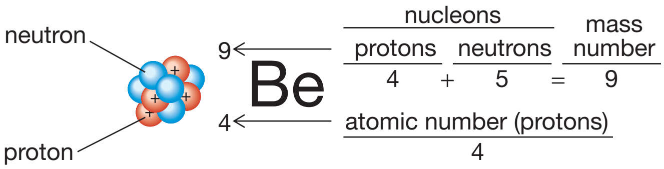
On the shore of Lake Ontario, just east of Toronto, Pickering Nuclear Power Stations A and B produce enough electricity to power a city of about 2 million people. Each domed building, of which there are eight, contains a **CANDU** nuclear reactor. Each building has thick concrete walls to contain the gamma radiation emitted during the nuclear reaction that provides the energy to generate electricity. The cylindrical building with the flat roof in Figure D1.30 is part of the plant's safety system. It contains low-pressure air that can capture any radioactive gases that might escape from the reactors.

How, exactly, does the energy produced by nuclear reactions generate electrical energy? Is the nuclear reaction that takes place within the reactor buildings the same as the nuclear reactions that occur within the Sun's core? In addition to gamma radiation, are any other types of radiation produced? How does the process of generating electricity from nuclear reactions compare to the processes that occur in a coal-fired power plant? In this lesson you will have an opportunity to answer these questions as you incorporate what you have already learned about energy transformations and electricity production with information about nuclear reactions.

CANDU: Canadian Deuterium Uranium Reactor; a nuclear reactor technology developed in Canada and now operating in Canada and six other countries

Describing the Nucleus

Every atom has a nucleus composed of **protons** and **neutrons**. The number of protons determines an element's identity. The number of protons is called the **atomic number**. For example, all beryllium atoms have 4 protons. Although all atoms of the same element must have the same number of protons, they can vary in mass due to differences in the number of neutrons they possess. For example, the most common type of beryllium is called beryllium-9. Since the nucleus of beryllium-9 has 4 protons and 5 neutrons, it has a **mass number** of 9. Since protons and neutron make up the nucleus, they are often referred to as **nucleons**; therefore, the beryllium-9 nucleus has a total of 9 nucleons. The nucleus of beryllium-9 can be concisely described using **nuclear notation** as follows.



Other forms of the beryllium atom, like beryllium-10, have a different number of nucleons (mass number) but the same atomic number. Beryllium-9 and beryllium-10 are **isotopes**. As you learn more about nuclear reactions, it will be important to differentiate between the isotopes of various elements.

DID YOU KNOW?

Beryllium-10 is formed in the upper atmosphere when cosmic rays collide with oxygen or nitrogen atoms.

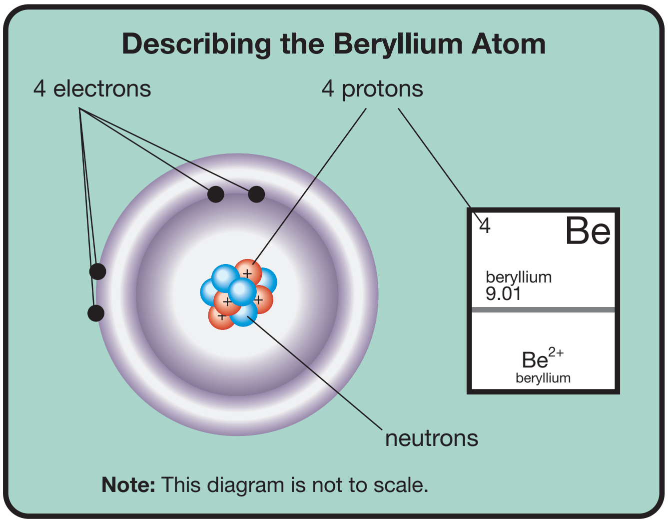


Figure D1.31: A beryllium atom is made up of protons, neutrons, and electrons. Here is one such representation.

- **proton:** a component of an atomic nucleus with a mass of 1 atomic mass unit and a charge of 1+
- **neutron:** a component of an atomic nucleus with a mass of 1 atomic mass unit and no net charge
- **atomic number:** the number of protons in the nucleus of an atom; determines the identity of an element
- **mass number:** the total number of protons and neutrons in an atom; frequently written after the name of an element to identify a specific isotope
- **nucleon:** the name applied to protons and neutrons (the parts of an atom's nucleus)
- **nuclear notation:** representation of an atom, $^{A}_{Z}X$, that lists the chemical symbol for the element (*X*), its atomic number (*Z*), and its mass number (*A*)
- **isotope:** a particular variety of an element as defined by its atomic mass

Practice

26. Complete the following table.

Isotope	Atomic Number	Mass Number	Number of . . .		
			Protons	Neutrons	Nucleons
hydrogen-2 (deuterium)					
carbon-13					

27. The masses of a proton, neutron, and an electron are as follows:

- proton: $1.007\,28 \times 10^{-3}$ kg/mol
- neutron: $1.008\,66 \times 10^{-3}$ kg/mol
- electron: 5.49×10^{-7} kg/mol

a. How many times larger are protons than electrons?

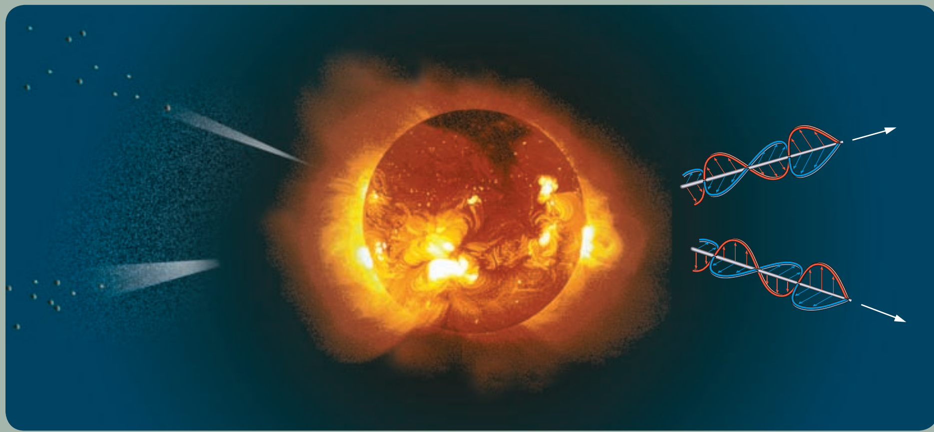
b. It is customary to delete the mass of electrons when calculating the atomic mass. Use your answers to question 27.a. to justify this practice.

28. Using nuclear notation, express the following isotopes.

a. uranium-235 **b.** uranium-238 **c.** polonium-210 **d.** polonium-218

Science Links

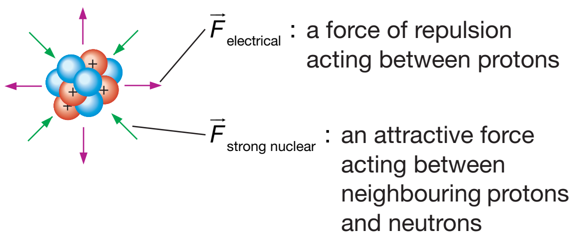
In Units B and C you learned that Earth's atmosphere and magnetic field provide a significant degree of shielding to protect organisms from the harmful effects of ionizing radiation from space. Some of this radiation is in the form of electromagnetic radiation: X-rays and gamma rays. Other forms of radiation consist of streams of fast-moving particles: electrons, protons, and helium nuclei.



Alpha Radiation

If a nucleus is comprised of protons and neutrons, a good question to ask is what keeps it together? After all, shouldn't the positive charge of such tightly packed protons repel one another? Recall from Unit C that the force between two charges increases exponentially in response to a reduction in their distance. Therefore, to keep a nucleus together, the forces at work within it must be greater than the force of repulsion between protons.

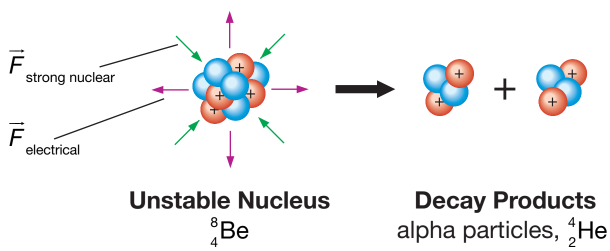
A Stable Nucleus—Balanced Forces in $^{9}_{4}$Be



A **strong nuclear force** is a force that attracts protons to neutrons, neutrons to neutrons, and even protons to protons. Although this force attracts all these particles to one another, it only acts between particles that are close enough to touch each other. The electrical force generated by repelling particles acts over any distance. Larger nuclei—those containing more protons—require neutrons to "dilute" the repulsive forces within the nucleus. In addition to spreading out the repulsive electrical force, neutrons increase the strong nuclear force by acting like glue to hold nucleons together. The **radioactive decay** demonstrated by unstable isotopes demonstrates the role of neutrons in balancing the forces within the nucleus.

Beryllium-8 is an unstable isotope when compared to beryllium-9. The difference of one neutron reduces the strong nuclear force relative to the force caused by the repulsion between protons. The instability caused by the imbalance between forces within the nucleus causes the beryllium-8 atom to break apart into two **alpha particles**. Alpha particles are nuclei composed of two protons and two neutrons, having a net charge of 2+. The alpha particles have the same composition as the nucleus of a helium atom and are often written as $^{4}_{2}$He. The release of alpha particles during nuclear decay is called **alpha radiation**. For beryllium-8, its radioactive decay is unusual in that both products happen to be alpha particles. In most situations, only one product of the decay is an alpha particle.

An Unstable Nucleus—Unbalanced Forces in $^{8}_{4}$Be



- **strong nuclear force:** an attractive force between nuclear particles that acts over short distances
- **radioactive decay:** a spontaneous change in which an unstable nucleus emits radiation
- **alpha particle:** a positively charged particle consisting of two neutrons and two protons, which is a helium nucleus
- **alpha radiation:** a stream of alpha particles emitted from unstable nuclei; one of the three principal types of nuclear radiation

The process of radioactive decay can be represented using a nuclear equation. When balancing a nuclear equation, the number of nucleons is conserved. Example Problem 1.3 shows how to balance a nuclear equation.

Example Problem 1.3

Many smoke detectors contain the isotope americium-241. Alpha particles emitted during the decay of americium-241 ionize molecules in the air, allowing an electric current to flow between two plates in the smoke detector. During a fire, smoke particles that come between these two plates interfere with the current, setting off the detector's alarm.

a. State the name of the process that produces an alpha particle.

b. Write a balanced nuclear equation describing the decay of americium-241 that results in an alpha particle and another product.

Solution

a. The process that releases an alpha particle is called alpha radiation.

b. Write the nuclear equation. Let ${}^{A}_{Z}X$ represent the unknown product.

Reactant **Products**

$$ {}^{241}_{95}\text{Am} \rightarrow \underset{\text{alpha particle}}{{}^{4}_{2}\text{He}} + \underset{\text{unknown product}}{{}^{A}_{Z}X} $$

step 1: In a table, list the mass numbers (total nucleons) and the atomic numbers of the reactant side and the products side of the nuclear equation.

	Reactant	Products
Mass Number	241	$4 + A$
Atomic Number	95	$2 + Z$

step 2: Determine the mass number and the atomic number of the unknown product. **Note:** The reactant side and the products side must have the same total.

$$241 = 4 + A \qquad 95 = 2 + Z$$
$$A = 237 \qquad Z = 93$$

The mass number and atomic number of the other product are 237 and 93, respectively.

step 3: Identify the other product, and write its nuclear notation.

atomic number 93 = neptunium, Np

Therefore, ${}^{A}_{Z}X = {}^{237}_{93}\text{Np}$.

step 4: Write the balanced nuclear equation.

$$ {}^{241}_{95}\text{Am} \rightarrow {}^{4}_{2}\text{He} + {}^{237}_{93}\text{Np} $$

Practice

29. Write the balanced nuclear equation showing the alpha decay for each isotope given.

a. beryllium-8

b. uranium-232

c. polonium-210

30. Each of the following atoms is a product of an alpha-decay reaction. Write a balanced nuclear equation for each.

a. uranium-235

b. plutonium-236

31. Radium-226 is an unstable isotope that decays to radon-222.

a. Write the balanced nuclear equation for this process.

b. Identify the type of radiation produced by the decay of radium-226.

Beta Radiation

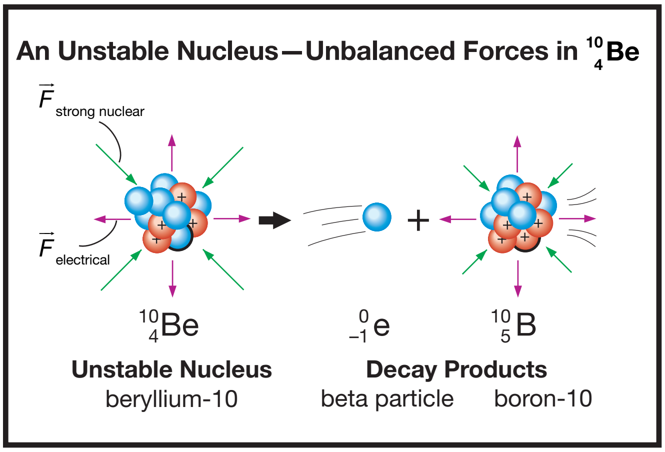


Figure D1.32

You have seen that an imbalance between the strong nuclear force and the electrical force within a nucleus results in an unstable nucleus. The instability within the nucleus of beryllium-10 leads to the emission of a **beta particle**—an electron. A beta particle is represented by the symbol $^{0}_{-1}e$.

A stream of negatively charged beta particles is called **beta radiation**. Even though a beta particle is an electron, the term *beta particle* is used to indicate that each particle originates from the nucleus and not from the orbiting electrons that participate in chemical bonding.

beta particle: a high-speed electron emitted from an unstable nucleus; the result of the change of a neutron to a proton during a nuclear reaction

beta radiation: a stream of beta particles emitted from unstable nuclei; one of three principle types of nuclear radiation

Reactant **Products**

$$\underset{\text{neutron}}{^{1}_{0}n} \rightarrow \underset{\text{beta particle}}{^{0}_{-1}e} + \underset{\text{proton}}{^{1}_{1}p}$$

	Reactant	Products
Mass Number	1	0 + 1
Atomic Number	0	−1 + 1
Note: The reactant and products sides of the equation balance.		

Beta particles are ejected from the nucleus when a neutron is converted into a proton. During **beta decay**, the number of nucleons comprising a nucleus does not change, but the atomic number does. The 1– charge of a beta particle is balanced by the conversion of a neutron into a proton, as demonstrated in the nuclear equation for the decay of beryllium-10 (Figure D1.32).

beta decay: a spontaneous change in which an unstable nucleus emits beta radiation

Beryllium-10 Decay

$$^{10}_{4}Be \rightarrow {}^{0}_{-1}e + {}^{10}_{5}B$$

	Reactant	Products
Mass Number	10	0 + 10
Atomic Number	4	−1 + 5
Note: The reactant and products sides of the equation balance.		

Since beta decay causes the conversion of one neutron into a proton, beryllium-10 nuclei are converted into boron-10 nuclei. The boron nucleus has one more proton (5) than the beryllium nucleus (4).

Example Problem 1.4

Carbon-14 is a radioactive isotope that emits beta radiation. Carbon-14 is found in the atmosphere and eventually finds its way into living systems. Once a plant or animal dies, the amount of carbon-14 remaining in the tissue can be used to estimate the number of years that have passed since the organism's time of death. This is done by using the half-life of carbon-14. To get a clearer picture of human history, archaeologists use carbon-14 dating to estimate the age of ancient remains, like teeth or bone fragments.

Use this information to write a balanced nuclear equation for the beta decay of carbon-14.

Solution

step 1: List the reactant and the products.

reactant: ${}^{14}_{6}\mathrm{C}$

products: ${}^{0}_{-1}\mathrm{e}$ and ${}^{A}_{Z}X$

step 2: In a table, list the mass numbers (total nucleons) and the atomic numbers of the reactant and the products.

	Reactant	Products
Mass Number	14	$0 + A$
Atomic Number	6	$-1 + Z$

step 3: Determine the mass number and the atomic number of the other product.

$$14 = 0 + a \qquad 6 = -1 + Z$$
$$A = 14 \qquad z = 7$$

The mass number and atomic number of the unknown product are 14 and 7, respectively.

step 4: Identify the unknown product, and write its nuclear notation.

atomic number 7 = nitrogen, N

Therefore, ${}^{A}_{Z}X = {}^{14}_{7}\mathrm{N}$.

step 5: Write the balanced nuclear equation.

$${}^{14}_{6}\mathrm{C} \rightarrow {}^{0}_{-1}\mathrm{e} + {}^{14}_{7}\mathrm{N}$$

Practice

32. Each isotope listed undergoes beta decay. Write a balanced nuclear equation showing the change that occurs.

a. krypton-87

b. silicon-32

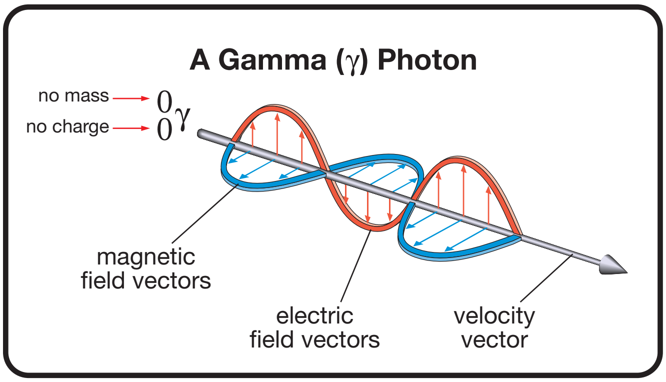
33. Each isotope listed is a product of beta decay. Use a balanced nuclear equation to determine the identity of the isotope that underwent nuclear change.

a. gallium-71

b. nickel-60

Gamma Radiation

Unlike alpha and beta radiation, gamma radiation is not comprised of a stream of charged particles. As you learned in Unit C, gamma radiation consists of a stream of gamma photons—the most energetic form of electromagnetic radiation.



Because a photon is a bundle of electromagnetic energy—consisting of electric and magnetic fields—photons have no mass or charge. The symbol for a gamma photon, $^{0}_{0}\gamma$, concisely communicates this information.

Gamma radiation is usually emitted as an additional product of alpha or beta decay, but it can be emitted on its own. In Unit C, when you were comparing forms of electromagnetic radiation, you discovered that gamma rays have even more energy than X-rays. As a result, gamma rays are very damaging when they are absorbed by biological molecules. This is why gamma radiation is frequently used in cancer therapy to kill cancerous cells.

Example Problem 1.5

Cobalt-60 is a source of gamma radiation that is frequently used to treat patients with cancer. Machines used in modern cancer therapy, like the one in the photograph, can focus narrow beams of gamma radiation from over 200 cobalt-60 sources to destroy cancer cells deep within the patient.

Write a balanced nuclear equation to describe the emission of beta and gamma radiation from a cobalt-60 source.

Solution

$^{60}_{27}\text{Co} \rightarrow {}^{0}_{0}\gamma + {}^{0}_{-1}\text{e} + {}^{A}_{Z}X$

	Reactant	Products
Mass Number	60	0 + 0 + a
Atomic Number	27	0 + −1 + *z*

Determine the mass number and the atomic number of the unknown product.

$$60 = 0 + 0 + A \qquad 27 = 0 + -1 + Z$$
$$A = 60 \qquad Z = 28$$

The product with an atomic number of 28 is nickel.

Therefore, $^{A}_{Z}X = {}^{60}_{28}\text{Ni}$.

Thus, the balanced nuclear equation is

$^{60}_{27}\text{Co} \rightarrow {}^{0}_{0}\gamma + {}^{0}_{-1}\text{e} + {}^{60}_{28}\text{Ni}$.

Shielding Nuclear Radiation

Radioactive materials are used in a number of specialized medical procedures. These materials are transported and stored in shielded containers that absorb the emitted particles or photons and ensure that radiation does not pass into the environment. Would the shielding requirements be different if the radioactive isotope in the vial were a source of alpha radiation or beta radiation? Why is shielding so important when working with these materials?

In Units B and C you discovered that high-energy radiation is capable of ionizing the material through which it passes, leading to the formation of free radicals. Ionizing radiation is harmful to living tissue—particularly to DNA, which is especially vulnerable to the damage caused by free radicals. This is why it is important to ensure that exposure to ionizing radiation is kept ALARA (as low as reasonably achievable).

Figure D1.33: Radioactive materials are stored and transported in specially shielded containers.

Alpha, beta, and gamma radiation are all classified as ionizing radiation because they are each capable of ionizing the material they penetrate. As you have seen in this lesson, each of these types of nuclear radiation has remarkably different properties. As a result, the type of material that is an effective shield for one type of radiation may not necessarily be effective for another. So, different types of shielding materials can be used for transporting isotopes or in the design of a nuclear reactor.

The effectiveness of a shielding material can be determined by placing it between a source of a particular radiation and a device that can detect the radiation, like a **Geiger counter**. The output of a Geiger counter displays the number of charged particles and/or photons that have entered the device. In the next activity you will have an opportunity to use an animated version of this kind of set-up.

Geiger counter: a device that detects and measures the intensity of ionizing radiation

Figure D1.34: A Geiger counter

Practice

34. Antimony-126, a beta particle, and a gamma photon are the three products of a nuclear reaction. Identify the isotope that undergoes a nuclear reaction to form these products.

35. Polonium-218 emits an alpha particle and a gamma photon. Identify the other product of the decay of polonium-218.

DID YOU KNOW?

Damage to DNA can come from hydroxyl radicals formed when water absorbs ionizing radiation. Hydroxyl radicals can react with the deoxyribose sugar within the DNA strand, causing mutation or significant damage to cause the death of the cell.

Utilizing Technology

Shielding Radiation

Science Skills
✓ Performing and Recording
✓ Analyzing and Interpreting

Purpose

You will use the applet "The Alpha, Beta, and Gamma of Radiation" from the Science 30 Textbook CD to determine which types of materials are capable of shielding alpha, beta, and gamma radiation.

Background

Before starting, familiarize yourself with the features of the applet. Select an isotope, select different barriers (shielding materials), and adjust the position of the Geiger counter. In the first part of the procedure, you will measure the radiation emitted by natural sources, often referred to as background radiation. You will then complete measurements of the radiation emitted from different isotopes as it travels through air and through other barriers.

Procedure

Obtain the "Shielding Radiation" handout from the Science 30 Textbook CD.

step 1: Set the Geiger counter 10 mm to the right of the shielding material.

step 2: Measure the background radiation. To do this, select "No isotope" for the isotope and "Air" for the barrier; then click on "Start Count." **Note:** The applet is set to collect data over five seconds.

step 3: Record the total radiation count from the Geiger counter in the appropriate place on the handout. Repeat this step two more times.

step 4: Repeat steps 2 and 3 with uranium-238, strontium-90, and cobalt-60 as the isotope. Record your results in the appropriate places.

step 5: Repeat steps 1 to 3 using paper, aluminium, and lead as the barrier. Record your results in the appropriate place.

1. Complete the data tables in the handout.

Analysis

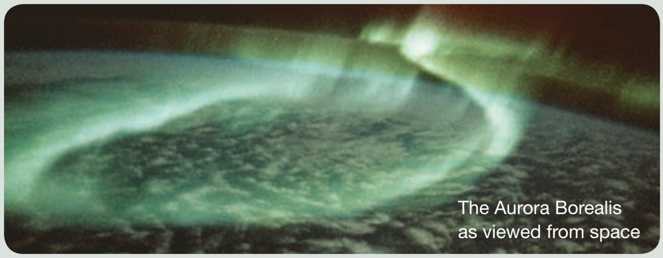
2. Rank the barriers tested from greatest to least shielding ability for each type of radiation.
3. Use the applet to collect data that allows you to write a balanced nuclear equation describing the decay reaction for each isotope. Explain how you used the data from the applet to write these equations.

Shielding with Solid Materials

The results from the "Shielding Radiation" activity demonstrate that the type of radiation emitted by a source must be considered before you can select an appropriate shielding material. Shielding involves using a material that absorbs the radiation emitted by an isotope. The size of the alpha particle makes it one of the easiest forms of radiation to absorb by sheilding, whereas the considerably smaller beta particle has the ability to penetrate denser substances, like those that were tested. Gamma sources are the most difficult to shield. They require thick walls of lead or, in the case of CANDU nuclear reactors, several metres of concrete. As you can see, shielding is an important technique in the safe use of radiation for many technologies.

Science Links

Shielding protects life on Earth from the harmful effects of ionizing radiation from space. You discovered in Unit C that Earth's protective shield consists of two parts: Earth's magnetic field and the molecules, like ozone, that make up Earth's atmosphere.

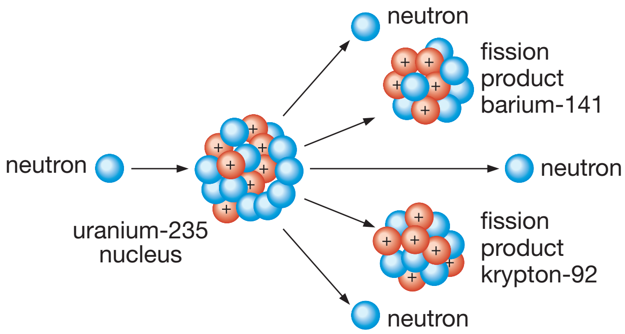


The Aurora Borealis as viewed from space

Nuclear Fission

Earlier you learned that radioactive decay involves atoms spontaneously changing from one element into another, and that a nuclear change is accompanied by a release of energy in the form of radiation. Radiation emitted during alpha and beta decay can possess sufficient energy to harm living tissue, but not enough energy to be used for large-scale energy production. Currently, the only application for the energy released by these processes is providing electricity and heat for deep-space probes. Using nuclear energy for the large-scale generation of electricity requires a different process.

Nuclear Fission of Uranium-235



$$^{235}_{92}\mathrm{U} + {}^{1}_{0}n \rightarrow 3\,{}^{1}_{0}n + {}^{92}_{36}\mathrm{Kr} + {}^{141}_{56}\mathrm{Ba}$$

	Reactants	Products
Mass Number	235 + 1 = 236	3 + 92 + 141 = 236
Atomic Number	92 + 0 = 92	0 + 36 + 56 = 92

Figure D1.35

The nuclear reaction used to release energy in CANDU reactors, like those at Pickering Nuclear Power Stations A and B, is **nuclear fission**. Nuclear fission involves splitting atoms. It was used in the first atomic bombs and is still used today to generate electricity for millions of homes, businesses, and industries in Canada and throughout the world. A fission reaction occurs when a large nucleus, such as uranium-235, is struck by a neutron and breaks into two smaller nuclei, called fission products. As shown in Figure D1.35, the fission of uranium-235 also yields three neutrons and high-energy gamma radiation which is not shown. View the "Nuclear Fission" applet, from the Science 30 Textbook CD, to see an animation of a fission reaction.

nuclear fission: a nuclear reaction in which a large nucleus splits into smaller nuclei or particles with the simultaneous release of energy

The kinetic energies of the neutrons and fission products add up to a lot of energy—much more than is released by a chemical reaction. In a nuclear reactor, this energy is transferred as heat to water surrounding the nuclear fuel.

Practice

36. The fission of uranium-235 can produce many different products. The following equations show one product of the fission of uranium-235. Use a balanced nuclear reaction to determine the unknown product, ${}_{Z}^{A}X$, in each reaction.

a. ${}_{92}^{235}\mathrm{U} + {}_{0}^{1}n \rightarrow 3\,{}_{0}^{1}n + {}_{Z}^{A}X + {}_{53}^{137}\mathrm{I}$

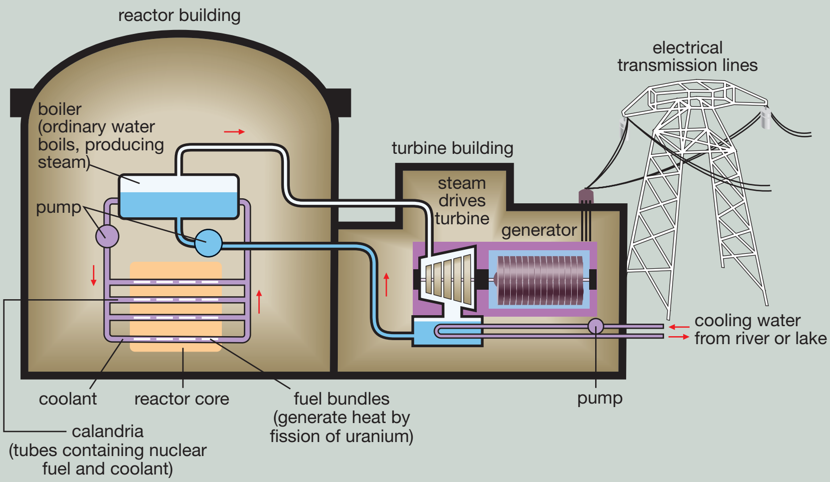
b. ${}_{92}^{235}\mathrm{U} + {}_{0}^{1}n \rightarrow 3\,{}_{0}^{1}n + {}_{Z}^{A}X + {}_{35}^{90}\mathrm{Br}$

DID YOU KNOW?

A small mass of uranium yields a lot of energy. For example, the fuel used for an entire year of operations at Pickering could fit into a double-car garage. In comparison, Alberta's newest coal-fired power plant, Genesee 3, produces about one-ninth of the energy using 1.9 million tonnes of coal per year. This is roughly equivalent to a pile of coal that covers a football field and has a height of a 45-storey building.

Electricity from Nuclear Fission—CANDU

Products of a fission reaction have large quantities of kinetic energy. If this energy can cause water to boil and become high-pressure steam, it can spin turbines, which can spin generators, which can generate electricity. Sound familiar? It should. This is very similar to the design of a conventional coal-fired power plant. A nuclear power plant enables the release of **intranuclear potential energy**, allowing it to be transformed into useful electricity. Nuclear power plants are similar to fossil fuel power plants in that they are both thermal sources of electricity. The best way to get an overview of how all this works is to take a quick tour of a generating station powered by a CANDU reactor.



intranuclear potential energy: energy stored within the nucleus of atoms

Figure D1.36: Cross section of a CANDU power plant

Utilizing Technology

Reactor Operation

Reactor Operation

Watch the video "Reactor Operation" from the Science 30 Textbook CD. Use the information from the video to answer the Analysis questions.

Science Skills

✓ Performing and Recording

Analysis

1. Prepare a table with three columns, and use the following headings: Similar Components, Similar Processes, and Unique Processes. In the first column, list the similar components found in coal-fired and nuclear power plants. In the second column, list the similar processes used in coal-fired and nuclear power plants. In the third column, list the processes that are unique to nuclear power plants.
2. Identify two functions of heavy water in a CANDU nuclear reactor.
3. Explain "Defence in Depth."
4. Justify the practices used to train nuclear-plant operators, including a careful selection of experienced individuals and participation in intensive training programs.

Practice

37. Refer to the cross section of a CANDU nuclear power plant (Figure D1.36) and to the cross section of a coal-fired power plant (Figure D1.29 on page 500). Compare these two methods of producing electricity by considering the following:

- energy source
- form of energy in energy source
- reaction used to release energy from the energy source
- list of energy transformations for water during the process
- method of converting kinetic energy into electrical energy

Controlling the Fission Reaction

Controlling the release of energy from the energy source is an important aspect of plant operation and design. In a coal-fired generating station, the release of energy can be controlled by adjusting the amount of pulverized coal that is fed into the furnace.

The energy released by a CANDU reactor is determined by the mass of uranium-235 that undergoes fission. As shown in Figure D1.35 on page 510, the fission of uranium-235 requires a supply of neutrons. Uranium-235 used in the CANDU process is in the form of uranium dioxide pellets assembled into cylindrical fuel bundles. Within the reactor, sections of the fuel bundles are exposed, allowing them to undergo fission. How does exposing a section of a fuel rod allow for the control of a fission reaction? Recall that the key to a fission reaction is neutrons. Controlling the neutrons that strike the U-235 regulates the mass of isotope that reacts and, therefore, the quantity of energy released by the reactor.

Figure D1.37: Fuel bundles are used to generate electricity in CANDU reactors.

One means of controlling neutrons within the reactor involves the use of **heavy water**. The higher density of heavy water acts to slow neutrons to a speed that is ideal for colliding with U-235 nuclei, initiating its fission. Heavy water is often referred to as a **moderator** when used to control the speed of neutrons in a nuclear reactor.

heavy water: water composed of two atoms of the heavier isotopes of hydrogen and one atom of oxygen

moderator: a substance of low molecular mass capable of reducing the speed of neutrons during the operation of a nuclear reactor

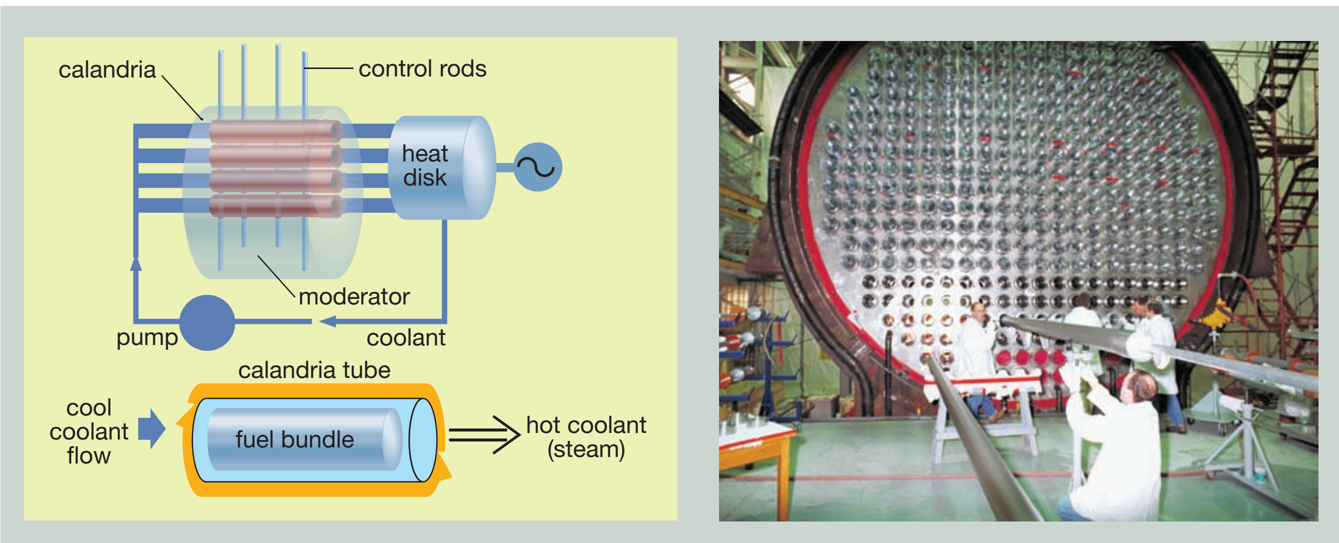


Figure D1.38: The core of a nuclear reactor is a calandria, composed of many long tubes in which the fuel rods are placed. The tubes containing the fuel rods are each surrounded by larger tubes containing coolant (heavy water). Thermal energy from the fission reaction in the fuel is transferred to the heavy water, converting the water into steam.

A second method of controlling neutrons and the energy output of the reactor is the use of control rods. Lowering the control rods further into the core of the reactor allows for greater absorption of neutrons, thereby decreasing the number of fission reactions that occur and reducing the energy output of the reactor.

The emergency-shutdown systems of a CANDU reactor are also based on controlling the neutrons that initiate fission reactions. The first emergency-shutdown system involves quickly inserting neutron-absorbing control rods into the reactor to immediately stop the reaction. The second involves the injection of neutron-absorbing liquid into the moderator.

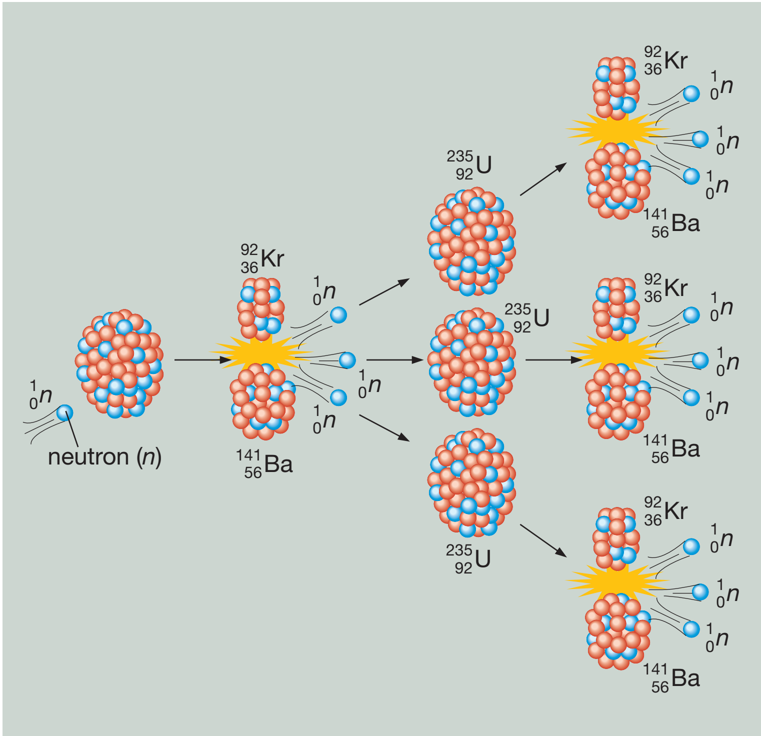
You may have noticed that all of the safety and control mechanisms mentioned for a CANDU reactor involve mechanisms to control neutrons. Previously, you discovered that the fission reaction of uranium-235 is initiated by a collision with a neutron. This collision then releases three neutrons as products. The proper control of neutrons produced by each fission reaction prevents an uncontrolled **chain reaction,** whereby an exponential increase in the number of fission reactions that occur results in an exponential release in energy.

A rapid energy release could occur due to poor control of fission reactions in the reactor or to poor control of the transfer of energy from the reactor. This could result in extensive damage, often called **nuclear meltdown**.

Figure D1.39: The meltdown that occurred at a nuclear power plant in Chernobyl, Ukraine, released radioactive materials into the environment. These materials were carried thousands of kilometres by winds.

DID YOU KNOW?

Cobalt-60 is an isotope created when cobalt-59 is used within adjuster rods of some CANDU reactors. Cobalt-60 undergoes beta decay and releases gamma radiation, making it useful for cancer radiotherapy and for sterilizing medical instruments.



chain reaction: a nuclear reaction that perpetuates itself; the release of neutrons during nuclear fission that initiates the fission of other atoms

nuclear meltdown: the result of improper control of a nuclear reaction within a reactor; the increase in the temperature of the core of a nuclear reactor, resulting in damage and increasing the risk of releasing radioactive substances into the environment

Reactor meltdowns, like the one that occurred on April 25, 1986, in Chernobyl, Ukraine, can result in the release of radioactive materials into the environment. Although the CANDU reactor is designed in such a way that a meltdown is extremely unlikely, the Chernobyl incident was such a frightening event that many people are still nervous about embracing nuclear power.

DID YOU KNOW?

Since 1991, children from the Ukraine and Belarus who were born with low-functioning immune systems—believed to be the result of the incident in Chernobyl—have been coming to Canada for a break from the exposure of radiation in their environment. These visits have allowed the children to strengthen their immune systems and, thus, increase their ability to fight simple infections like colds.

Mass-Energy Equivalence—$E = mc^2$

A pellet of uranium used in nuclear power plants has a mass of about 7 g; but it can release the same quantity of energy as 3.5 barrels (556.5 L) of oil, 480 000 L of natural gas, or 807 kg of coal. How can such a small pellet of uranium be an enormous source of energy?

The answer can be traced back to the work of Albert Einstein, who in the early 1900s published articles describing a theory of general relativity (pertaining to gravity) and a special theory of relativity (describing the motion of particles approaching the speed of light). One of the predictions of the special theory was that mass could be converted into energy and energy could be converted into mass. In other words, mass and energy are interchangeable. Previously you have always balanced reactions with respect to the law of conservation of mass, focusing on either the number of nucleons or the number of moles of each type of atom involved. Einstein's theory redefined people's understanding of the nature of matter and energy.

In Einstein's theory, mass is not just the sum of its constituent parts; it is also the sum of the kinetic, potential, and mass energy. Energy is now considered to be the only commodity in the universe that cannot be created or destroyed. Any difference between the masses of the products and the reactants of a process must be the result of mass having been converted into energy. Einstein was able to describe the relationship between the change in mass and its conversion to energy by using his famous equation, $E = mc^2$.

It is more descriptive to express Einstein's equation as $\Delta E = \Delta mc^2$, where

$$\Delta E = \text{change in energy}$$

$$\Delta m = \text{change in mass}$$
$$= \text{mass of products} - \text{mass of reactants}$$

$$c = \text{speed of light}\left(3.00 \times 10^8 \text{ m/s}\right)$$

Because the square of the speed of light is an enormous number, a small change in mass corresponds to a very large energy change. You can see how this equation is used in Example Problem 1.6.

Example Problem 1.6

In the fission of 1 mol of beryllium-8, the mass of the products is determined to be 2.29×10^{-5} kg less than the mass of the reactants. Calculate the change in energy that corresponds with this change in mass. Identify whether this reaction is exothermic or endothermic.

Solution

$$\Delta m = 2.29 \times 10^{-5} \text{ kg}$$

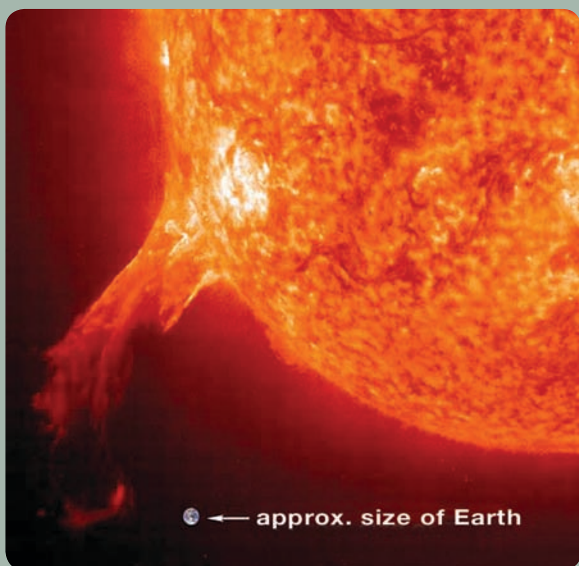
$$c = 3.00 \times 10^{8} \text{ m/s}$$

$$\Delta E = ?$$

$$\begin{aligned}\Delta E &= \Delta mc^2 \\ &= \left(2.29 \times 10^{-5} \text{ kg}\right)\left(3.00 \times 10^{8} \text{ m/s}\right)^2 \\ &= 2.06 \times 10^{12} \text{ kg}\bullet\text{m}^2/\text{s}^2 \\ &= 2.06 \times 10^{12} \text{ J}\end{aligned}$$

The energy change for 1 mol of beryllium-8 is 2.06×10^{12} J. Since the mass of the products is **less** than the mass of the reactants, the missing mass must have converted into energy. Therefore, the reaction is exothermic.

Science Links: Fuel for the Sun



The radiation that the Sun pours into space originates from nuclear reactions deep within its core. Every second, approximately 3.8×10^{26} J of energy is emitted from the Sun's surface. Using the equation $E = mc^2$, this means that the Sun must be converting about 4.2×10^9 kg of mass into energy every second. Although this seems like a very large value, this loss of mass is actually quite small compared to the total mass of the Sun, which is about 2×10^{30} kg.

The electromagnetic radiation emitted from stars can be analyzed by astronomers to provide valuable information about the composition and temperature of these distant suns. This work is described in Unit C.

Example Problem 1.7

Earlier, you learned that beta decay involves the conversion of a neutron into a proton and a beta particle: ${}^{1}_{0}n \rightarrow {}^{0}_{-1}\text{e} + {}^{1}_{1}p$. Use the "Masses of Subatomic Particles and Radiation" table from the Science Data Booklet to calculate the change in mass between the products and the reactants. Identify whether this reaction is exothermic or endothermic.

Solution

$${}^{1}_{0}n \rightarrow {}^{0}_{-1}\text{e} + {}^{1}_{1}p$$

Determine the mass of the reactant and the mass of the products.

$$m_{\text{reactant}} = 1.008\ 66 \times 10^{-3}\ \text{kg}$$

$$\begin{aligned} m_{\text{products}} &= m_{\text{beta}} + m_{\text{proton}} \\ &= \left(1\ \cancel{\text{mol}}\right)\left(0.000\ 549 \times 10^{-3}\ \text{kg}/\cancel{\text{mol}}\right) \\ &\quad + \left(1\ \cancel{\text{mol}}\right)\left(1.007\ 28 \times 10^{-3}\ \text{kg}/\cancel{\text{mol}}\right) \\ &= 1.007\ 829 \times 10^{-3}\ \text{kg} \end{aligned}$$

Determine the change in mass.

$$\begin{aligned} \Delta m &= m_{\text{reactant}} - m_{\text{products}} \\ &= 1.008\ 66 \times 10^{-3}\ \text{kg} - 1.007\ 829 \times 10^{-3}\ \text{kg} \\ &= 0.000\ 831 \times 10^{-3}\ \text{kg} \\ &= 8.31 \times 10^{-7}\ \text{kg} \end{aligned}$$

The change in mass is 8.31×10^{-7} kg when 1 mol of neutrons is converted. Since the mass of the products is less than the mass of the reactant, this reaction is exothermic.

Example Problem 1.8

The fission of uranium-235 that occurs in a CANDU reactor involves the following reaction.

$${}^{235}_{92}\text{U} + {}^{1}_{0}n \rightarrow 3\,{}^{1}_{0}n + {}^{141}_{56}\text{Ba} + {}^{92}_{36}\text{Kr}$$

Calculate the change in mass between the reactants and the products for this reaction and the corresponding energy change.

Solution

$${}^{235}_{92}\text{U} + {}^{1}_{0}n \rightarrow 3\,{}^{1}_{0}n + {}^{92}_{36}\text{Kr} + {}^{141}_{56}\text{Ba}$$

Determine the mass of the reactants.

$$\begin{aligned} m_{\text{reactants}} &= m_{\text{U}} + m_{n} \\ &= \left(1\ \cancel{\text{mol}}\right)\left(235.043\ 92 \times 10^{-3}\ \text{kg}/\cancel{\text{mol}}\right) \\ &\quad + \left(1\ \cancel{\text{mol}}\right)\left(1.008\ 66 \times 10^{-3}\ \text{kg}/\cancel{\text{mol}}\right) \\ &= 236.052\ 58 \times 10^{-3}\ \text{kg} \end{aligned}$$

Determine the mass of the products. Recall that three neutrons are produced during each fission reaction.

$$\begin{aligned} m_{\text{products}} &= 3m_{n} + m_{\text{Ba}} + m_{\text{Kr}} \\ &= \left(3\ \cancel{\text{mol}}\right)\left(1.008\ 66 \times 10^{-3}\ \text{kg}/\cancel{\text{mol}}\right) \\ &\quad + \left(1\ \cancel{\text{mol}}\right)\left(91.926\ 11 \times 10^{-3}\ \text{kg}/\cancel{\text{mol}}\right) \\ &\quad + \left(1\ \cancel{\text{mol}}\right)\left(140.914\ 41 \times 10^{-3}\ \text{kg}/\cancel{\text{mol}}\right) \\ &= 235.866\ 50 \times 10^{-3}\ \text{kg} \end{aligned}$$

Determine the change in mass.

$$\begin{aligned} \Delta m &= m_{\text{reactants}} - m_{\text{products}} \\ &= 236.052\ 58 \times 10^{-3}\ \text{kg} - 235.866\ 50 \times 10^{-3}\ \text{kg} \\ &= 0.186\ 08 \times 10^{-3}\ \text{kg} \\ &= 1.8608 \times 10^{-4}\ \text{kg} \end{aligned}$$

The change in mass is 1.8608×10^{-4} kg.

Now, determine the energy change.

$$\begin{aligned} \Delta E &= \Delta m c^{2} \\ &= \left(1.8608 \times 10^{-4}\ \text{kg}\right)\left(3.00 \times 10^{8}\ \text{m/s}\right)^{2} \\ &= 1.67 \times 10^{13}\ \text{kg}\bullet\text{m}^{2}/\text{s}^{2} \\ &= 1.67 \times 10^{13}\ \text{J} \end{aligned}$$

The energy change for 1 mol of uranium-235 is 1.67×10^{13} J.

Vast Amounts of Energy from a Tiny Fraction of Total Mass

When completing Example Problems 1.7 and 1.8, you calculated the change in mass of a nuclear process using more accurate masses for subatomic particles and nuclides. The mass difference for nuclear reactions is often very small—often a fraction of a gram. Recall that only the unaccounted mass (Δm) is converted into energy. Einstein's theory states that when mass "disappears," it must be converted into some form of energy. In the operation of a nuclear reactor, the energy released during the fission of uranium is converted into heat and, eventually, into electricity.

Practice

38. Calculate the change in mass and corresponding energy change per mole of uranium-235 in the nuclear reactions given. Use masses given in the Science Data Booklet and those provided in the following table.

Nuclide	Mass (10^{-3} kg/mol)
bromine-91, ${}^{91}_{35}\text{Br}$	90.916 27
lanthanum-142, ${}^{142}_{57}\text{La}$	141.899 71
strontium-94, ${}^{94}_{38}\text{Sr}$	93.915 29
xenon-140, ${}^{140}_{54}\text{Xe}$	139.918 43

a. ${}^{1}_{0}n + {}^{235}_{92}\text{U} \rightarrow 2\,{}^{1}_{0}n + {}^{94}_{38}\text{Sr} + {}^{140}_{54}\text{Xe}$

b. ${}^{1}_{0}n + {}^{235}_{92}\text{U} \rightarrow 3\,{}^{1}_{0}n + {}^{91}_{35}\text{Br} + {}^{142}_{57}\text{La}$

39. Calculate the change in mass that would correspond to a release of 2.0×10^{14} J of energy.

Concerns About Nuclear Waste

You learned in this lesson that the small change in mass that occurs to the uranium-235 within a CANDU reactor can be used to meet the energy demands of huge numbers of people. In 2003, the 17 operating nuclear power plants in Canada produced almost 62 000 spent fuel bundles. For comparison, the space these bundles would occupy is less than the size of two classrooms within a school. You also learned that the spent fuel contains the products of fission reactions, which may emit ionizing radiation for many years. How is spent nuclear fuel dealt with? What concerns do people have about nuclear waste?

In Canada, spent fuel from reactors still contains a small amount of unreacted uranium-235 and is first stored under water in the nuclear power plant. The water in the deep pools absorbs thermal energy released by the fission of the remaining isotope and acts as a shield, preventing the release of radiation. After a few years in the pools, spent fuel bundles are moved into concrete canisters and stored above ground. Currently, there is no long-term storage facility for spent nuclear fuel in Canada. Such a facility, when developed, would have to ensure that the containers of waste remain intact and isolated. Current plans suggest that a long-term storage facility could be developed deep within the granite rock formation of the Canadian Shield. A major concern about the development of a long-term storage facility for nuclear waste is the possibility of accidentally releasing radioactive substances during transport.

DID YOU KNOW?

Some military submarines operate using uranium fission reactions as a power source. Because of the large quantity of energy contained within nuclear fuels, like uranium, a nuclear submarine can operate for ten years without refuelling. Some icebreaker ships and aircraft carriers are also nuclear powered. The main disadvantage of nuclear-powered vessels is the risk of reactor damage or meltdown. Unless contained, the reactor damage or meltdown could expose the crew and the environment to ionizing radiation and radioactive isotopes. Once decommissioned, nuclear vessels must also be properly dismantled. This involves the removal and long-term storage of radioactive components. The estimated cost of a submarine is $30 million.

Nuclear Fusion

Thus far, you have studied alpha, beta, and gamma decay and nuclear fission. The final type of nuclear reaction to consider is **nuclear fusion**. In one sense, nuclear fusion is the opposite of nuclear fission: *fusion* means "to bring together," whereas *fission* means "to break apart."

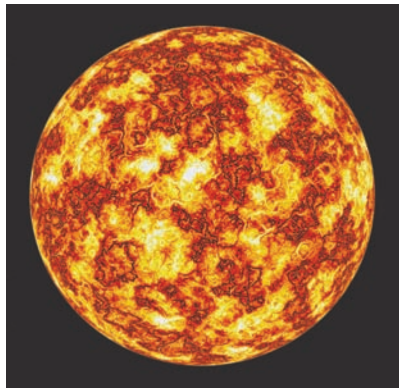
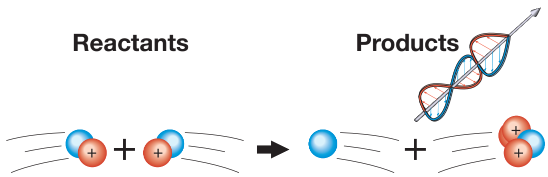


Figure D1.40: Nuclear fusion is the source of the Sun's energy.

A Fusion Reaction

Reactants Products



Nuclear Equation

$$^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{0}_{0}\gamma + ^{1}_{0}n + ^{3}_{2}He$$

nuclear fusion: a process in which two smaller nuclei join to form a larger nucleus, with the simultaneous release of energy

deuterium: a heavy isotope of hydrogen with one proton and one neutron in the nucleus

In a fusion reaction, a heavy isotope of hydrogen called **deuterium**, nuclides collide at high speed to form a product, helium-3, that has a larger nucleus than either of the reactants. Recall from Unit C that hydrogen fusion reactions occur deep within the Sun, where extremely high temperatures and pressures exist. Also recall that the fusion of hydrogen within the Sun emits radiation that is the primary energy source for photosynthesis—the process that provides food either directly or indirectly for all organisms on Earth.

DID YOU KNOW?

All elements are born in stars. Fusion reactions within stars produce larger elements from hydrogen. The largest atom made by fusion within the Sun is iron, which has 26 protons. Larger elements—like gold, platinum, and uranium—are formed in supernovas (exploding stars). Supernovas leave behind gas and dust that serve as raw materials for making new planets.

Practice

40. For each fusion reaction given, complete the equation and identify the unknown product, $^{A}_{Z}X$.

a. $^{2}_{1}H + ^{3}_{1}H \rightarrow ^{1}_{0}n + ^{A}_{Z}X$ **b.** $^{14}_{7}N + ^{1}_{1}H \rightarrow ^{0}_{0}\gamma + ^{A}_{Z}X$

41. Calculate the energy change for each reaction in question 40. Determine whether the fusion reaction results in a release of energy. Support your answer.

Solar Fusion Reactions

hydrogen to deuterium: $^{1}_{1}H + ^{1}_{1}H \rightarrow ^{0}_{+1}e + ^{2}_{1}H$

Note: The symbol, $^{0}_{+1}e$, represents a positron—an elementary particle with the same mass as an electron, but with a positive charge.

deuterium to helium-3: $^{2}_{1}H + ^{1}_{1}H \rightarrow ^{0}_{0}\gamma + ^{3}_{2}He$

helium-3 to helium-4: $^{3}_{2}He + ^{3}_{2}He \rightarrow 2\,^{1}_{1}H + ^{4}_{2}He$

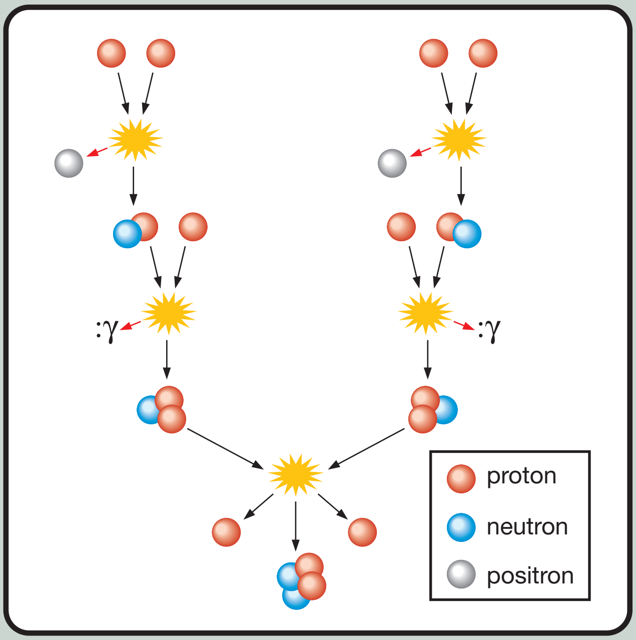
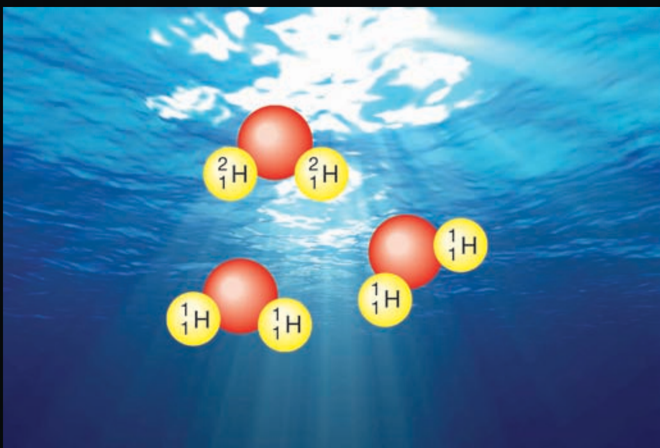


Figure D1.41

The series of fusion reactions shown in Figure D1.41 identifies the conversion of some of hydrogen—which makes up over 70% of the Sun's mass—into helium. Fusion reactions like those occurring within the Sun's core are considered to be possible energy-releasing reactions for reactors in power plants on Earth.

From the Science 30 Textbook CD, view the "Nuclear Fusion" applet to see a simulation of the conditions that must be created within a fusion reactor. In the "Is Fusion the Energy Source of the Future" activity, you will investigate the state of fusion research and the potential for energy from fusion to meet world energy demands.



It might surprise you to know that the deuterium necessary for fusion reactions is plentiful in seawater. Deuterium and other isotopes to be considered for use in fusion reactions are considered inexhaustible, making fusion a **renewable energy** source. Energy production that relies on the combustion of fossil fuels or nuclear fission is considered to be **non-renewable energy**. In the next chapter you will learn more about technologies to develop renewable energy sources.

renewable energy: energy derived from continuously available sources that can be replenished in a short period of time

non-renewable energy: energy derived from sources that will become depleted because they are not able to be replenished in a short period of time

Utilizing Technology

Is Fusion the Energy Source of the Future?

Science Skills
- ✓ Performing and Recording
- ✓ Analyzing and Interpreting

Purpose

You will investigate the current state of fusion research and the development of electricity generation from fusion reactions.

Procedure

Use the Internet, library, or other sources to research this issue. You may work on your own or within in a small group. Use the focus questions as a guide to develop an information package, brochure, model, or brief presentation to identify the status of the development of systems that use fusion power.

Focus Questions

1. What is nuclear fusion? Identify the reactants used in fusion reactions currently being studied.
2. Describe the conditions necessary for fusion to occur. Describe the challenges in attempting to create a fusion reactor that can sustain these conditions.
3. Describe the status of current efforts to produce a reactor that can sustain a fusion reaction.
4. Identify advantages and disadvantages of fusion power as an energy source.

1.4 Summary

Radiation refers to the energy released during nuclear reactions. Ionizing radiation released by nuclear reactions takes three main forms: alpha, beta, and gamma. The energy provided by nuclear fission reactions is currently used to generate electricity in many countries, helping to meet the world's energy needs. Fission and other nuclear reactions result in some mass being converted into energy. The amount of energy associated with a reaction can be calculated using the equation $\Delta E = \Delta mc^2$. Nuclear fusion may, some day, join fission as a process for meeting the world's energy needs.

1.4 Questions

Knowledge

1. For the nucleus ${}^{92}_{36}\text{Kr}$, identify the

a. atomic number **b.** charge **c.** mass number **d.** number of nucleons

2. Define the following terms.

a. radioactive decay **b.** nuclear fission **c.** nuclear fusion

3. List the similarities and differences between a coal-fired power plant and a nuclear power plant.

4. Describe how the fission chain reaction is controlled in a CANDU nuclear reactor.

5. Identify and explain one risk and one benefit associated with the use of nuclear fission reactions for generating electricity.

Applying Concepts

6. Balance each reaction and identify the unknown product, ${}^{A}_{Z}X$. For each reaction, state the type of nuclear change shown.

a. ${}^{14}_{6}\text{C} \rightarrow {}^{0}_{-1}\text{e} + {}^{A}_{Z}X$ **b.** ${}^{241}_{95}\text{Am} \rightarrow {}^{A}_{Z}X + {}^{237}_{93}\text{Np}$ **c.** ${}^{3}_{1}\text{H} + {}^{2}_{1}\text{H} \rightarrow {}^{1}_{0}n + {}^{A}_{Z}X$ **d.** ${}^{A}_{Z}X + {}^{1}_{0}n \rightarrow 3\,{}^{1}_{0}n + {}^{107}_{44}\text{Ru} + {}^{130}_{50}\text{Sn}$

e. ${}^{90}_{38}\text{Sr} \rightarrow {}^{A}_{Z}X + {}^{90}_{39}\text{Y}$ **f.** ${}^{226}_{88}\text{Ra} \rightarrow {}^{A}_{Z}X + {}^{222}_{86}\text{Rn}$ **g.** ${}^{129}_{53}\text{I} \rightarrow {}^{0}_{0}\gamma + {}^{A}_{Z}X + {}^{129}_{54}\text{Xe}$

7. Is nuclear energy from the fission of uranium a renewable or non-renewable energy source? Provide a reason for your answer.

8. A possible reaction for fusion power involves a fusion between helium-3 and deuterium nuclei. The products of the reaction are helium-4 and a proton.

a. Present the process described as a balanced nuclear equation.

b. Calculate the change in mass and the corresponding energy change for the fusion between helium-3 and deuterium nuclei.

9. The following table shows the amount of energy released by physical, chemical, and nuclear changes. Identify the type of change for each, and determine how many times greater the energy release is compared to condensing water vapour.

Change	Energy Released (kJ/mol)	Type of Change (physical, chemical, or nuclear)	How Many Times Greater Than Condensing Water Vapour
condensing water vapour $H_2O(g) \rightarrow H_2O(l)$ + energy	40.7		
combusting methane (a component of natural gas) $CH_4(g) + 2\,O_2(g) \rightarrow CO_2(g) + 2\,H_2O(g)$ + energy	802		
fission of uranium-235 ${}^{1}_{0}n + {}^{235}_{92}\text{U} \rightarrow 3\,{}^{1}_{0}n + {}^{92}_{36}\text{Kr} + {}^{141}_{56}\text{Ba}$	1.67×10^{10}		
fusion of deuterium and tritium ${}^{2}_{1}\text{H} + {}^{3}_{1}\text{H} \rightarrow {}^{1}_{0}n + {}^{4}_{2}\text{He}$	1.82×10^{9}		

Chapter 1 Summary

Since the Industrial Revolution, new technologies, changes in lifestyle, and human population growth have caused an exponential increase in energy use. The world's demand for energy is largely met by the combustion of fossil fuels, like coal and oil. As part of the effort to supplement fossil fuel energy, nuclear technologies have also been used. In the next chapter you will examine renewable resources, how they have helped meet world energy demands, and how likely they will take on an increasing role in the future.

Summarize Your Learning

In this chapter you learned a number of new terms, concepts, and techniques for problem solving. You will have a much easier time recalling and applying the information you have learned if you take some time to organize it into some sort of pattern. Now that you have come to the end of the chapter, this is an appropriate time to focus on the patterns within the things you have learned.

Since the patterns have to be meaningful to you, there are some options about how you can create this summary. Each of the following options is described in "Summarize Your Learning Activities" of the Reference Section. Choose one of these options to create a summary of the key concepts and important terms in Chapter 1.

Option 1: Draw a concept map or a web diagram.	**Option 2:** Create a point-form summary.	**Option 3:** Write a story using key terms and concepts.	**Option 4:** Create a colourful poster.	**Option 5:** Build a model.	**Option 6:** Write a script for a skit (a mock news report).

Chapter 1 Review Questions

Knowledge

1. Define *energy*. Then list and define the types of energy studied in Chapter 1.
2. Describe the general trend in world energy use between 1850 and 2000. Provide a reason for the trend.
3. Compare total energy use and per capita energy use between developing countries and developed countries.
4. Provide reasons why Canada's per capita energy use is higher than that of the United States.
5. Define *energy efficiency*. Identify examples that promote improved energy efficiency. Explain how improvements to energy efficiency would affect total energy use in Canada.
6. Describe the relationship between a country's gross domestic product (GDP) and its total energy use.
7. How does per capita energy use in Alberta compare to other Canadian provinces? Account for any differences.
8. Predict the effect that a rapid industrialization of developing countries will have on the world's total energy use during the next few decades.
9. List the non-renewable energy sources described in Chapter 1.
10. State the main fuel used by First Nations communities before the arrival of Europeans.
11. For each energy source given, state how it is formed and how it is used.

    a. coal **b.** petroleum **c.** natural gas
12. Which fossil fuel, listed in question 11, is currently the world's top energy source?
13. Explain why extracting petroleum from oil sand is much more energy intensive than conventional drilling.

14. List some applications of hydrocarbons other than as energy sources.

15. Explain why energy conversions can never be 100% efficient.

16. Describe the energy transformations that occur in a coal-fired power plant during the production of electricity.

17. Define each term given, and provide a technological application.

    a. radioactive decay **b.** nuclear fission **c.** nuclear fusion

18. Compare nuclear fission with nuclear fusion.

19. List the series of energy transformations that occur within a generating station that uses a CANDU nuclear reactor.

20. Identify technical difficulties associated with developing fusion power.

Applying Concepts

21. List the factors you would need to consider in order to estimate the energy required to manufacture a paper coffee cup and lid.

22. Refer to Figure D1.42. Describe the trends for predicted changes to population and electricity demand in China. Provide an explanation for the prediction for electricity demand in light of the predicted population change.

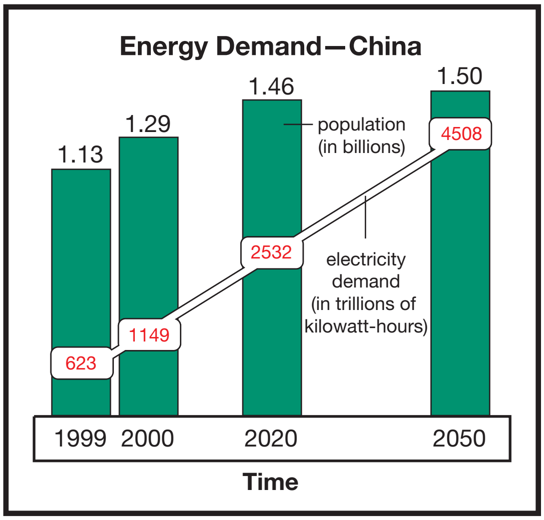


Figure D1.42

23. Describe the sequence of energy conversions for energy radiated by the Sun that becomes energy used to heat up leftover chili in your microwave oven.

24. Use the Internet to research the following questions.

    a. Describe how hybrid automobiles work differently than conventional gas-powered automobiles.

    b. Compare the fuel economy of hybrid automobiles with conventional gas-powered automobiles.

    c. Provide a reason why individuals would be motivated to purchase hybrid cars.

25. Use standard heats of formation and the balanced combustion equations to calculate the energy change per mole for the combustion of the fuel listed.

    a. ethane, $C_2H_6(g)$ (a component of natural gas)

    $C_2H_6(g) + 3.5\ O_2(g) \rightarrow 2\ CO_2(g) + 3\ H_2O(g)$

    b. propane, $C_3H_8(g)$ (a common barbecue fuel)

    $C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(g)$

26. Draw an energy diagram for the combustion of propane that demonstrates the products have a lower chemical potential energy than the reactants and shows the energy released during the reaction.

27. Use your answer from question 25.b. to calculate the efficiency of a barbecue that produces 795 kJ of useful output energy for cooking when it burns 1 mol of propane.

28. Calculate the chemical potential energy necessary for a power plant to generate 1.6×10^9 J if it is 44% efficient.

29. Radium was discovered in the early 1900s and was at one time used in many consumer products because of its luminescence. The use of radium in consumer products stopped when it became known that it produces ionizing radiation. Write a balanced nuclear equation for the alpha decay of radium-226.

30. The deuterium-deuterium fuel cycle proposed for nuclear fusion is as follows:

    $${}^{2}_{1}\text{H} + {}^{2}_{1}\text{H} \rightarrow {}^{1}_{0}n + {}^{3}_{2}\text{He}$$

    Calculate the energy change of this reaction per mole of helium-3.